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(54) Title: RECOMBINANT AAV GENOME ENCODING IMMUNODEFICIENCY VIRUS PROTEIN

(57) Abstract

The present invention provides adeno-associated virus (AAV) materials and methods which are useful for DNA delivery to cells. More particularly, the invention provides recombinant AAV (rAAV) genomes, comprising adeno-associated virus inverted terminal repeats flanking DNA sequences encoding an immunodeficiency virus protein operably linked to promoter and polyadenylation sequences, methods for packaging rAAV genomes, stable host cell lines producing rAAV and methods for delivering genes of interest to cells utilizing the rAAV. Particularly disclosed are rAAV useful in generating immunity to human immunodeficiency virus-1 and in therapeutic gene delivery for treatment of neurological disorders.

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RECOMBINANT AAV GENOME ENCODING IMMUNODEFICIENCY VIRUS PROTEIN

This application is a continuation-in-part of co-pending U.S. Patent Application Serial No. 08/254,358 filed June 6, 1994.

FIELD OF THE INVENTION

The present invention generally relates to adeno-associated virus (AAV) materials and methods which are useful for delivering DNA to cells. More particularly, the invention relates to recombinant AAV (rAAV) genomes, to methods for packaging rAAV genomes, to stable cell lines producing rAAV and to methods for delivering genes of interest to cells utilizing the rAAV.

BACKGROUND

Adeno-associated virus (AAV) is a replication-deficient parvovirus, the single-stranded DNA genome of which is about 4.7 kb in length including 145 nucleotide inverted terminal repeat (ITRs). See Figure 1. The nucleotide sequence of the AAV2 genome is presented in Srivastava *et al.*, *J. Virol.*, *45*: 555-564 (1983). *Cis*-acting sequences directing viral DNA replication (ori), encapsidation/packaging (pkg) and host cell chromosome integration (int) are contained within the ITRs. Three AAV promoters, p5, p19, and p40 (named for their relative map locations), drive the expression of the two AAV internal open reading frames encoding rep and cap genes. The two rep promoters (p5 and p19), coupled with the differential splicing of the single AAV intron (at nucleotides 2107 and 2227), result in the production of four rep proteins (rep 78, rep 68, rep 52, and rep 40)from the rep gene. Rep proteins possess multiple enzymatic properties which are ultimately responsible for replicating the viral genome. The cap gene is expressed from the p40 promoter and it encodes the three capsid proteins VP1, VP2, and VP3. Alternative and non-consensus translational start sites are responsible for the production of the

three related capsid proteins. A single consensus polyadenylation site is located at map position 95 of the AAV genome. The life cycle and genetics of AAV are reviewed in Muzyczka, *Current Topics in Microbiology and Immunology, 158*: 97-129 (1992).

When AAV infects a human cell, the viral genome integrates into chromosome 19 resulting in latent infection of the cell. Production of infectious virus does not occur unless the cell is infected with a helper virus (for example, adenovirus or herpesvirus). In the case of adenovirus, genes E1A, E1B, E2A, E4 and VA provide helper functions. Upon infection with a helper virus, the AAV provirus is rescued and amplified, and both AAV and adenovirus are produced.

AAV possesses unique features that make it attractive as a vector for delivering foreign DNA to cells. AAV infection of cells in culture is noncytopathic, and natural infection of humans and other animals is silent and asymptomatic. Moreover, AAV infects most (if not all) mammalian cells allowing the possibility of targeting many different tissues *in vivo*. Kotin *et al.*, *EMBO J.*, *11*(13): 5071-5078 (1992) reports that the DNA genome of AAV undergoes targeted integration on chromosome 19 upon infection. Replication of the viral DNA is not required for integration, and thus helper virus is not required for this process. The AAV proviral genome is infectious as cloned DNA in plasmids which makes construction of recombinant genomes feasible. Furthermore, because the signals directing AAV replication, genome encapsidation and integration are contained within the ITRs of the AAV genome, the internal approximately 4.3 kb of the genome (encoding replication and structural capsid proteins, rep-cap) may thus be replaced with foreign DNA such as a gene cassette containing a promoter, a DNA of interest and a polyadenylation signal. Another significant feature of AAV is that it is an extremely

stable and hearty virus. It easily withstands the conditions used to inactivate adenovirus (56° to 65°C for several hours), making cold preservation of rAAV-based vaccines less critical. Finally, AAV-infected cells are not resistant to superinfection.

Various groups have studied the potential use of AAV in treatment of disease states. Patent Cooperation Treaty (PCT) International Publication No. WO 91/18088 published November 28, 1991 and the corresponding journal article by Chatterjee *et al., Science, 258*: 1485-1488 (1992) describe the transduction of intracellular resistance to human immunodeficiency virus-1 (HIV-1) in human hematopoietic and non-hematopoietic cell lines using an rAAV encoding an antisense RNA specific for the HIV-1 TAR sequence and polyadenylation signal. The review article Yu *et al., Gene Therapy, 1*: 13-26 (1994) concerning gene therapy for HIV-1 infection lists AAV as a possible gene therapy vector for hematopoietic stem cells. The use of rAAV vectors as a delivery system for stable integration and expression of genes (in particular the cystic fibrosis transmembrane regulator gene) in cultured airway epithelial cells is described in PCT International Publication No. WO 93/24641 published December 9, 1993 and in the corresponding journal article by Flotte *et al., Am. J. Respir. Cell Mol. Biol., 7*: 349-356 (1992). Gene therapy involving rAAV in the treatment of hemoglobinopathies and other hematopoietic diseases and in conferring cell-specific multidrug resistance is proposed in PCT International Publication No. WO 93/09239 published May 13, 1993; Muro-Cacho *et al., J. Immunol., 11*: 231-237 (1992); LaFace *et al., Virol., 162*: 483-486 (1988); and Dixit *et al., Gene, 104*: 253-257 (1991). Therapeutic gene delivery into glioma cells is proposed in Tenenbaum *et al., Gene Therapy, 1* (Supplement 1): S80 (1994).

A relatively new concept in the field of gene transfer is that immunization may be effected by the product of a transferee gene. Several attempts at "genetic immunization" have been reported including direct DNA injection of influenza A nucleoprotein sequences [Ulmer *et al., Science, 259*: 1475-1749 (1993)],

biolistic gun immunization with human growth hormone sequences [Tang *et al.*, *Nature, 356*: 152-154 (1992) and infection with retroviral vectors containing HIV-1 gp160 envelope protein sequences [Warner *et al.*, *AIDS RESEARCH AND HUMAN RETROVIRUSES, 7*(8): 645-655 (1991)]. While these approaches appear to be feasible, direct DNA inoculation may not provide long-lasting immune responses and serious questions of safety surround the use of retroviral vectors. The use of AAV for genetic immunization is a novel approach that is not subject to these problems.

An obstacle to the use of AAV for delivery of DNA is the lack of highly efficient schemes for encapsidation of recombinant genomes. Several methods have been described for encapsidating rAAV genomes to generate recombinant viral particles. These methods all require *in trans* AAV rep-cap and adenovirus helper functions. The simplest involves transfecting the rAAV genome into host cells followed by co-infection with wild-type AAV and adenovirus. See, for example, U.S. Patent No. 4,797,368 issued January 10, 1989 to Carter and Tratschin, and the corresponding journal article by Tratschin *et al.*, *Mol. Cell. Biol.*, *5*(11): 3251-3260 (1985). This method, however, leads to unacceptably high levels of wild-type AAV. Another general strategy involves supplying the AAV functions on a second plasmid (separate from the rAAV genome) that is co-transfected with the rAAV plasmid. See, for example, Hermonat *et al.*, *Proc. Natl. Acad. Sci. USA, 81*: 6466-6470 (1984) and Lebkowski *et al.*, *Mol. Cell. Biol.*, *8*(10): 3988-3996 (1988). If no sequence overlap exists between the two plasmids, then wild-type AAV production is avoided as is described in Samulski *et al.*, *J. Virol.*, *63*(9): 3822-3828 (1989). This strategy is inherently inefficient, however, due to the requirement for three separate DNA transfer events (co-transfection of two plasmids as well as infection with adenovirus) to generate rAAV particles. Large scale production of rAAV by this method is costly and is subject to variations in transfection efficiency.

Vincent *et al.*, *Vaccines, 90*: 353-359 (1990) reports that a cell line expressing rep-cap functions could be used to package rAAV. Such methods still requires transfection of the rAAV genome into the cell line and the resulting titer of rAAV reported was very low (only about 10^3 infectious units/ml). Dutton, *Genetic Engineering News, 14*(1): 1 and 14-15 (January 15, 1994) reports that Dr. Jane Lebkowski of Applied Immune Sciences manufactures rAAV using chimeric AAV/Epstein-Barr virus plasmids that contain a recombinant AAV genome, the hygromycin resistance gene and the EBV ori P fragment and EBNA gene. The plasmids are transfected into cells to generate stable cell lines. The stable cell lines are then transfected with wild-type AAV rep-cap functions and infected with adenovirus to produce rAAV. Like the method of Vincent, the Lebkowski packaging method requires both transfection and infection events to generate rAAV particles.

There thus exists a need in the art for efficient methods of packaging rAAV genomes and for specific rAAVs useful as vectors for DNA delivery to cells.

SUMMARY OF THE INVENTION

The present invention provides recombinant AAV (rAAV) genomes useful for delivering non-AAV DNA of interest to a cell. The rAAV genomes of the invention include AAV ITRs flanking non-AAV DNA sequences of interest and lack rep-cap sequences encoding functional rep-cap proteins. If it is desirable to express the DNA of interest as a polypeptide in the cell, the rAAV genome also includes a (constitutive or regulatable) promoter and a polyadenylation signal operably linked to the DNA of interest to form a gene cassette. The gene cassette may also include intron sequences to facilitate processing of the RNA transcript in mammalian host cells. A presently preferred gene cassette includes the following DNA segments: (1) the cytomegalovirus (CMV) immediate early promoter, (2) the rabbit β-globin intron, (3) simian immunodeficiency virus (SIV) or human immunodeficiency (HIV) rev and

envelope (gp160) genes, and (4) the rabbit β-globin polyadenylation signal. The rAAV genomes of the invention may be assembled in vectors useful for transfection of cells which are permissible for infection with a helper virus of AAV (*e.g.*, adenovirus, E1-deleted adenovirus or herpesvirus). A vector of the invention which contains a rAAV genome including the foregoing preferred gene cassette, a neomycin resistance gene, and wild-type AAV rep-cap sequences was deposited in *E. coli* DH5 cells with the American Type Culture Collection (ATCC), 12301 Parklawn Drive, Rockville, Maryland 20852, on June 1, 1994 and was assigned ATCC Accession No. 69637.

Presently preferred rAAV genomes include the SIV rev and envelope (gp160) genes, or the HIV rev and envelope genes, as the non-AAV DNA(s) of interest. Also preferred are rAAV genomes which contain sequences encoding proteins which may ameliorate neurological disorders such as: sequences encoding nerve growth factor (NGF), ciliary neurotrophic factor (CNTF), brain-derived neurotrophic factor (BDNF), neurotrophins 3 and 4/5 (NT-3 and 4/5), glial cell derived neurotrophic factor (GDNF), transforming growth factors (TGF), and acidic and basic fibroblast growth factor (a and bFGF); sequences encoding tyrosine hydroxylase (TH) and aromatic amino acid decarboxylase (AADC); sequences encoding superoxide dimutase (SOD 1 or 2), catalase and glutathione peroxidase; sequences encoding interferons, lymphokines, cytokines and antagonists thereof such as tumor necrosis factor (TNF), CD4 specific antibodies, and TNF or CD4 receptors; sequences encoding GABA receptor isoforms, the GABA synthesizing enzyme glutamic acid decarboxylase (GAD), calcium dependent potassium channels or ATP-sensitive potassium channels; and sequences encoding thymidine kinase. Also contemplated by the invention are rAAV genomes including globin, oncogene, ras, and p53 sequences. Recombinant AAV genomes including antisense nucleotides that

affect expression of certain genes such as cell death suppressor genes (*e.g.*, bcl-2) or that affect expression of excitatory amino acid receptors (*e.g.*, glutamate and NMDA receptors) are also contemplated for modulating neurological disorders.

Other DNA sequences of interest contemplated by the invention include sequences from pathogens including: HIV-1 and HIV-2 (sequences other than rev and gp160 sequences); human T-lymphotrophic virus types I and II; respiratory syncytial virus; parainfluenza virus types 1-4; measles virus; mumps virus; rubella virus; polio viruses types 1-3; influenza virus types A, B and C; non-human influenza viruses (avian, equine, porcine); hepatitis virus types A, B, C, D and E; rotavirus; norwalk virus; cytomegaloviruses; Epstein-Barr virus; herpes simplex virus types 1 and 2; varicella-zoster virus; human herpes virus type 6; hantavirus; adenoviruses; chlamydia pneumoniae; chlamydia trachomatis; mycoplasma pneumoniae; mycobacterium tuberculosis; atypical mycobacteria; feline leukemia virus; feline immunodeficiency virus; bovine immunodeficiency virus; equine infectious anemia virus; caprine arthritis encephalitis virus; and visna virus.

Cell lines of the invention are stably transfected with both rAAV genomes of the invention and with copies of the AAV rep and cap genes. Preferred cell lines are mammalian cell lines, for example, HeLa cell lines. Infection of the cell lines of the invention with AAV helper virus results in packaging of the rAAV genomes as infectious rAAV particles. A presently preferred stable cell line is the A64 HeLa cell line which was deposited with the ATCC on June 1, 1994 and was assigned ATCC Accession No. CRL 11639. The present invention also provides stable cell lines containing AAV rep and cap sequences but no rAAV genome.

Recombinant AAV generated by the foregoing packaging process are useful for delivering the DNA of interest to cells. *In vivo*, rAAV may be used as antisense delivery vectors, gene therapy vectors or vaccine (*i.e.*, genetic immunization) vectors. Treatment of disease conditions including, for example,

AIDS; neurological disorders including cancer, Alzheimer's disease, Parkinson's disease, Huntington's disease, and autoimmune diseases such as multiple sclerosis, trauma, depression, migraine, pain or seizure disorders; adult T-cell leukemia; tropical spastic paraparesis; upper and lower respiratory tract infections; upper and lower respiratory tract infections; measles; mumps; rubella; polio; influenza; influenza; hepatitis; hepatitis; hepatitis; hepatitis; hepatitis; diarrhea; diarrhea; systemic cytomegalovirus infections; mononucleosis-like illness; systemic Epstein-Barr virus infections; classic infectious mononucleosis; systemic herpes simplex types 1 and 2 infections; genital herpes simplex infections; chickenpox; roseola; febrile illness due to human herpes virus type 6; pneumonia and adult respiratory distress syndrome; upper and lower respiratory tract infections; conjunctivitis; upper and lower respiratory tract infections; upper and lower respiratory tract infections; genital tract infections; upper and lower respiratory tract infections; pulmonary and extrapulmonary tuberculosis; systemic infections due to atypical mycobacteria; feline leukemia; feline AIDS; bovine AIDS; equine infectious anemia; arthritis and encephalitis in goats; and pneumonia and encephalitis in sheep are contemplated by the invention. As a vaccine vector, rAAV delivers a gene of interest to a cell and the gene is expressed in the cell. The vaccine vectors may be used to generate intracellular immunity if the gene product is cytoplasmic (*e.g.*, if the gene product prevents integration or replication of a virus). Alternatively, extracellular/systemic immunity may be generated if the gene product is expressed on the surface of the cell or is secreted.

A host (especially a human host) may be immunized against a polypeptide of a disease-causing organism by administering to the host an immunity-inducing amount of a rAAV of the invention which encodes the polypeptide. Immunization of a human host with a rAAV of the invention involves administration by inoculation of an immunity-inducing dose of the virus by the parenteral route

(*e.g.*, by intravenous, intramuscular or subcutaneous injection), by surface scarification or by inoculation into a body cavity. Typically, one or several inoculations of between about 1000 and about 10,000,000 infectious units each, as measured in susceptible human or nonhuman primate cell lines, are sufficient to effect immunization of a human host. Virus to be used as a vaccine may be utilized in liquid or freeze-dried form (in combination with one or more suitable preservatives and/or protective agents to protect the virus during the freeze-drying process). For gene therapy (*e.g.*, of neurological disorders which may be ameliorated by a specific gene product) a therapeutically effective dose of a rAAV of the invention which encodes the polypeptide is administered to a host in need of such treatment. The use of rAAV of the invention in the manufacture of a medicament for inducing immunity in, or providing gene therapy to, a host is contemplated.

BRIEF DESCRIPTION OF THE DRAWING

Numerous other aspects and advantages of the present invention will be apparent upon consideration of the following detailed description thereof, reference being made to the drawing wherein:

Figure 1 is a schematic representation of the AAV genome;

Figure 2 is a schematic representation of plasmid psub201 which was the source of AAV2 sequences utilized in the examples;

Figure 3A through 3B is a flow diagram of the construction of a rAAV genome of the invention in vector pAAV/DMV/SIVrev-gp160;

Figure 4 is a flow diagram of the construction of the vector pAAV/CMV/SIVrev-gp160/neo/rep-cap useful to generate a stable cell line producing rAAV of the invention; and

Figure 5 is a schematic representation of a method for packaging rAAV utilizing stable host cell lines of the invention.

DETAILED DESCRIPTION OF THE DRAWING

The present invention is illustrated by the following examples relating to the production and use of rAAV of the invention. Example 1 describes the construction of a vector including a rAAV genome containing the SIV rev and envelope (gp160) genes, while Example 2 describes the construction of a vector including the AAV rep-cap genes and a neomycin resistance gene. Example 3 sets out the construction of a vector to be used to generate stable cell lines producing rAAV from the vectors described in Examples 1 and 2. The generation of stable cell lines producing rAAV encoding the SIV rev and gp160 proteins is detailed in Example 4. Example 5 sets out a preferred procedure for purifying rAAV from stable cell lines of the invention. Example 6 describes the generation of stable cell lines expressing the AAV rep-cap genes. Example 7 presents results of infection of various mammalian cells and cell lines with the rAAV described in Example 4 which show that gp160 protein is expressed in the infected cells. Example 8 describes the generation of stable cell lines producing a rAAV that includes the β-galactosidase gene as a DNA of interest and that is useful as a positive control virus for expression of a DNA of interest in target cells or tissues. Example 9 presents the results of experiments in which rAAV of the invention was used to express a DNA of interest *in vivo*. Example 10 describes methods contemplated by the invention for increasing the titer of rAAV produced by stable cell lines.

Example 1

A vector including a rAAV genome containing a SIV rev and envelope (gp160) gene cassette was constructed from an existing plasmid designated psub201 [Samulski *et al., supra*]. Figure 2 is a diagram of plasmid psub201 wherein restriction endonuclease sites are shown and abbreviated as follows: P, PvuII; X, XbaI; B, BamHI; H, HindIII; and N, NaeI. The plasmid contains a modified wild-type AAV2 genome cloned between the PvuII restriction sites. The DNA sequence of the wild-type AAV2 genome is set out in SEQ ID NO: 1. The AAV2 sequence was modified to include convenient restriction sites. Specifically, two XbaI restriction sites were added via linker addition at sequence positions 190 and 4484. These sites are internal to 191 bp inverted terminal repeats (ITRs) which included the 145 bp ITRs of the AAV genome. The insertion of these sites allows the complete removal of the internal 4.3 kb fragment containing the AAV rep-cap genes upon XbaI digestion of the plasmid. In Figure 2, the 191 bp ITRs are designated by inverted arrows.

The rAAV genome vector of the invention (pAAV/CMV/SIVrev-gp160) was generated in several steps.

First, plasmid psub201 was digested with XbaI and the approximately 4 kb vector fragment including the AAV ITRs was isolated. A CMV gene expression cassette was then inserted between the AAV ITRs by blunt end ligation. The CMV expression cassette was derived as a 1.8 kb XbaI - AflIII DNA fragment from the vector pCMV-NEO-BAM described in Karasuyama *et al., J. Exp. Med., 169*: 13-25 (1989). Prior to ligation, the molecular ends were filled in using the Klenow fragment of DNA polymerase I. The CMV expression cassette contained a 750 bp portion of the CMV immediate early promoter, followed by a 640 bp intron and a 360 bp polyadenylation signal sequence which were derived from the rabbit β-globin gene. Between the intron and poly A sequences were two cloning sites: a unique

BamHI site and two flanking EcoRI restriction sites. The resulting vector was named pAAV/CMV. See Figure 3A wherein restriction endonuclease cleavage sites are shown and abbreviated as follows: B, BamHI; E, EcoRI; N, NaeI; and P, PvuII.

Second, the pAAV/CMV expression vector was linerized at the BamHI site and sticky ends were blunted with Klenow. A PCR-generated, 2.7 kb SIV subgenomic fragment containing the rev and envelope (gp160) sequences [SEQ ID NO: 2, Hirsch *et al.*, *Nature, 339:* 389-392 (1989)] was cloned into the blunt-ended BamHI site. The resulting recombinant AAV genome vector, pAAV/CMV/SIVrev-gp160, is 8.53 kb in length. See Figure 3B wherein restriction endonuclease cleavage sites are shown and abbreviated as follows: N, NaeI and P, PvuII. The vector contains the following DNA segments in sequence: (1) an AAV ITR, (2) the CMV promoter, (3) the rabbit β-globin intron, (4) the SIV rev and envelope sequences, (5) the rabbit β-globin polyadenylation signal, and (6) an AAV ITR. In transient transfection assays of human 293 cells, this vector resulted in high levels of expression of the SIV gp160 protein as determined by radioimmunoprecipitation assays using polyclonal sera from monkeys infected with SIV.

The invention specifically contemplates substitution by standard recombinant DNA techniques of the following sequences for the SIV rev/envelope sequences in the foregoing vector: HIV-1 rev/envelope sequences (the HIV-1_{MN} rev/envelope sequence is set out in SEQ ID NO: 3); nerve growth factor [Levi-Montalcini, *Science, 237*: 1154-1162 (1987)]; ciliary neurotrophic factor [Manthorpe *et al.*, beginning at p. 135 in *Nerve Growth Factors*, Wiley and Sons (1989)]; glial cell derived neurotrophic factor [Lin *et al.*, *Science, 260*: 1130-1132 (1993)]; transforming growth factors [Puolakkainen *et al.*, beginning at p. 359 in *Neurotrophic Factors*, Academic Press (1993)]; acidic and basic fibroblast growth factors [Unsicker *et al.*, beginning at p. 313 in *Neurotrophic Factors*, Academic Press (1993)]; neurotrophin 3 [Maisonpierre *et al.*, *Genomics, 10*: 558-568 (1991)]; brain-derived

neurotrophic factor [Maisonpierre, *supra*]; neurotrophin 4/5 [Berkemeier *et al.*, *Neuron, 7*: 857-866 (1991)]; tyrosine hydroxylase [Grima *et al.*, *Nature, 326*: 707-711 (1987)]; and aromatic amino acid decarboxylase [Sumi *et al.*, *J. Neurochemistry, 55*: 1075-1078 (1990)].

Example 2

A plasmid designated pSV40/neo/rep-cap which contains the AAV rep-cap genes and a neomycin resistance gene was constructed to be used in conjunction with the rAAV genome vector described in Example 1 to generate a stable cell line producing rAAV.

A plasmid designated pAAV/SVneo (Samulski *et al.*, *supra*) was digested with EcoRI and BamHI to release a 2.7 kb insert including a 421 bp portion of the SV40 early promoter, a 1.4 kb neomycin resistance gene, and a 852 bp DNA fragment containing the SV40 small t splice site and SV40 polyadenylation signal. This released insert was cloned into the EcoRI and BamHI sites of pBLUESCRIPT KS+ (Stratagene, La Jolla, CA) to generate the 5.66 kb plasmid pSV40/neo. Next, the approximately 4.3 kb DNA fragment containing the AAV rep-cap genes, derived from the digestion of psub201 with XbaI as described in Example 1, was ligated into the XbaI restriction site of pSV40/neo to create the plasmid pSV40/neo/rep-cap (about 10 kb). The construction of this plasmid is detailed in first half of Figure 4 wherein restriction endonuclease sites are shown and abbreviated as follows: B, BamHI; E, EcoRI; HindIII; P, PvuII; N, NotI; RV, EcoRV; and X, XbaI. This plasmid was functional in transient assays for rep and cap activity and was itself ultimately used to derive stable cell lines (see Example 5 below).

Example 3

A final vector to be used to generate stable cell lines producing rAAV was generated from vector pAAV/CMV/SIVrev-gp160 (Example 1) and plasmid pSV40/neo/rep-cap (Example 2).

The construction entailed removing the neo-rep-cap gene cassette from pSV40/neo/rep-cap and inserting it into a unique NaeI site in pAAV/CMV/SIVrev-gp160 (see Figure 3B). Specifically, vector pAAV/CMV/SIVrev-gp160/neo/rep-cap was made by agarose gel band isolating a 7.0 kb EcoRV-NotI DNA fragment containing the SV/neo and rep-cap expression domains from pSV40/neo/rep-cap. The sticky ends of the fragment were blunted with Klenow and the fragment was ligated into the blunt-ended NaeI site of pAAV/CMV/SIVrev-gp160. See Figure 4. Vector pAAV/CMV/SIVrev-gp160/neo/rep-cap (ATCC 69637) contains the following elements: (1) the rAAV genome; (2) AAV rep-cap genes; and (3) the neomycin resistance gene.

Example 4

The vector pAAV/CMV/SIVrev-gp160/neo/rep-cap was used to generate stable cells lines containing both the rAAV genome of the invention and AAV rep-cap genes.

HeLa cells at 70% confluency were transfected with 10 μg of pAAV/CMV/SIVrev-gp160/neo/rep-cap plasmid DNA in 100 mm dishes. Cells were transfected for 6 hours after formation of DOTAP/DNA complexes in serum minus media as prescribed by the manufacturer's protocol (Boehringer-Mannheim, Indianapolis, IN). Following the removal of the transfection medium, DMEM media containing 10% fetal bovine serum was added to the cells. Three days later, media supplemented with 700 μg/ml Geneticin (Gibco-BRL, Gaithersburg, MD) was used to select for cells that stably expressed the neomycin resistance gene. Fresh Geneticin

containing DMEM media was added every four days. Geneticin resistant clones were selected 10-14 days after selective media was added. A total of fifty-five colonies were selected and transferred to 24-well plates and expanded for further analysis.

The fifty-five neomycin resistant HeLa cell lines were initially screened for functional rep gene activity; twenty-one scored positive. Rep gene activity was assayed by infecting the cell lines with adenovirus type 5 (Ad5). Infection by adenovirus transactivates the rep and cap genes. This results in the replication of the rAAV genome and subsequent encapsidation of these sequences into infectious rAAV particles. A schematic representation of rAAV production is shown in Figure 5. Following maximum Ad5-induced cytopathic effect (CPE; rounding of cells and 90% detachment from the culture flask), cell lysates were prepared and Hirt DNA (low molecular weight DNA) was isolated [Hirt, *J. Mol. Biol.*, *26*: 365-369 (1967)]. Southern blot analysis was used to visualize the synthesis of recombinant AAV (rAAV) replicative forms (single strand, monomeric, and dimeric forms). Control wells not receiving Ad5 were always negative. Cell lines with high relative levels of rep gene activity were selected for further study.

To assay for cap gene functionality, cell lines were infected with Ad5 and clarified lysates prepared after the development of maximum CPE. The cell lysates, Ad5, and wild-type AAV were used to infect HeLa cells. Following the development of Ad5 induced CPE (72 hr), Hirt DNA was isolated and Southern blot analysis performed. Cell line lysates that gave rise to gp160 hybridizable rAAV (SIV gp160) replicative sequences were scored positive for capsid production.

An infectious unit/ml (IU/ml) titer of rAAV produced by each cell line was derived by co-infecting C12 cells (exhibiting stable rep and cap gene expression) with Ad5 and a serial ten-fold dilution of the clarified cell line lysate to be tested. After maximum Ad5-induced CPE, Hirt DNA was isolated and Southern blot analysis

performed to detect the presence of rAAV replicative forms. The end-point dilution that produced visible monomeric and dimeric replication intermediates was taken as the titer. Titer estimation was based on two to four replicate experiments.

Results of characterization of eight of the fifty-five cell lines are shown in Table 1 below wherein "ND" indicates a value was not determined.

TABLE 1

Cell Line	Rep Function	Cap Function	Titer (IU/ml)
A5	++	+	10^4
A11	++++	+	10^5
A15	++++	+	10^5
A37	++++	+	ND
A60	+++++	-	$<10^1$
A64	+++++	+	10^6
A69	++	-	ND
A80	++++	+	10^5

Cell line A64 (ATCC CRL 11639) produced a high titer of rAAV (10^6 iu/ml) in clarified lysates. This titer is approximately 1000-fold higher than the titer of rAAV reported by Vincent *et al., supra.*

The rAAV produced by the various cell lines was also tested for its ability to express SIV gp160 in HeLa cells infected with the recombinant virus. Concentrated stocks of rAAV produced by the eight stable cell lines listed in Table 1 were generated. Cell lysates containing rAAV particles were subjected to step

density gradient (CsCl) purification. After desalting dialysis and heat-inactivation of Ad5, the rAAV particles were used to infect (transduce) HeLa cells in culture. Two lines of investigation were pursued. First, the transduced cells were tested for the presence of SIV gp160-specific mRNA by performing RT-PCR on total RNA collected 72 hours after transduction. Primers specific for SIV gp160 amplified a predicted 300 bp fragment only in the presence of reverse transcriptase and Taq polymerase; samples run without reverse transcriptase were uniformly negative. Second, HeLa cells were transduced with various dilutions of the same rAAV/SIV stock as described above and, at 72 hours post transduction, indirect immunofluorescence was performed on the infected cells. At all dilutions tested (out to 1:200), cells positive for the SIV gp160 protein were detected; lower dilutions clearly had more positive cells.

The A64 cell line was tested for wild-type AAV production by a standard method. The cell line was infected with adenovirus to produce rAAV as a lysate. The lysate was then used to infect normal HeLa cells either: (i) alone; (ii) with adenovirus; or (iii) with adenovirus and wild-type AAV. As a control, HeLa cells were infected with adenovirus and wild-type AAV without rAAV. Hirt DNA was prepared and analyzed by Southern blotting (two different blots) for replicating forms of either rAAV or wild-type AAV. No wild-type AAV was detected in A64 cells not exposed to wild-type AAV.

Because the present invention involves the establishment of stable cell lines containing not only copies of the AAV rep and cap genes, but also of the rAAV genome (with ITRs flanking DNA of interest), rAAV is produced by merely infecting the cell line with adenovirus. Transfection of exogenous DNA is not required, thereby increasing the efficiency of rAAV production compared to previously

described methods. Other significant features of the invention are that no wild-type AAV is produced and that scale-up for production of rAAV is easy and is limited only by normal constraints of cell growth in culture.

Example 5

A method to isolate and purify rAAV from stable (producer) cell lines was developed.

Producer cells (for example, the A64 cells of Example 4) were seeded at a cell density of 3 x 10^6 producer cells per 175 cm^2 surface area in growth medium. Cells reached a density of about 8 x 10^6 cells after 16-18 hours, and were then infected with adenovirus (Ad5) at a multiplicity of infection (moi) of 5 for 1-2 hours in growth medium. A 15 ml infection volume was used, and after the 1-2 hour infection, 10 ml of growth medium was added to each flask to obtain a final volume of 25 ml. [Alternatively, Ad5 may be added directly by: removing all but 15 ml of growth medium and adding Ad5 in a volume of 10 ml (diluted in HBSS) to give a final volume of 25 ml.]

Cells were harvested at about 48-60 hours after infection when most cells released from the flask after a vigorous shake. The cells were then stained with trypan blue to determine the percentage of viable cells. It is desirable for greater than 80% to be viable. Cells were then transferred to 250 ml disposable conical bottles (Corning) and pelleted at 1000 x g for 15 minutes at 4°C. The resulting supernatant was removed saving an aliquot and the cells were suspended in TM buffer (50mM Tris, pH 8.0, and 1mM $MgCl_2$) at a density of 5 x 10^6 cells/ml. The cells were subjected to three cycles of freeze/thaw on dry ice with vortexing 2 minutes between each thaw. The lysed cells were than heated to 56°C for 30 minutes to 1 hour with vortexing every 7.5 minutes during the last thaw. Ten percent deoxycholate was added to the lysate to a final concentration of 1%, and the mixture was incubated at

37°C for 30 minutes with intermittent vortexing to achieve complete lysis. If necessary to achieve complete lysis, the mixture was sonicated 3 times on maximum setting for 2 minutes each time. A hemocytometer was used to confirm complete cell lysis. Cell debris was pelleted at 2000 x g for 15 minutes at 4°C. The rAAV containing supernatant was saved.

The rAAV was isolated using a 1.31 g/ml CsCl cushion. Twenty-one ml of lysate supernatant was layered on a 14 ml CsCl cushion in a SW-28 tube, and spun 16,000 rmp, 10°C for 16 hours. The resulting supernatant was aspirated and the rAAV pellet was washed with HBSS to remove residual CsCl. The pAAV pellet was re-dissolved in 20mM Tris pH 8, 150mM NaCl, 1mM $MgCl_2$ (TMN buffer) in the smallest volume manageable (about 500 μl/pellet) and let hydrate overnight. It was then heated to 56°C for 30 minutes with vortexing every 5 minutes. At this endpoint, the virus was dialyzed against the TMN buffer to remove all traces of cesium if the virus was not going to be further purified.

The rAAV may be further purified by isopycnic banding. This is appropriate under conditions in which the virus is to be administered *in vivo*. The hydrated rAAV was brought up to a CsCl density of 1.41 g/ml, and then spun in an SW-41 tube at 30K for 48 hours at 10°C. The top portion of the gradient containing adenovirus (density 1.34 - 1.36 g/ml) was discarded and the remaining portion of the CsCl gradient was diluted with TMN down to a buoyant density of less than 1.1 g/ml. rAAV was then pelleted by an overnight spin at > 60,000 x g. The rAAV was resuspended in a minimal amount of TMN buffer supplemented with 1% gelatin. For efficient hydration, the pellet was allowed to sit overnight at 4°. The rAAV was then aliquoted and stored at 20°C.

Example 6

Concurrent with the generation of the stable cells described in Example 4, stable HeLa cell lines were established by similar methods which contained rep-cap genes but no rAAV genome using plasmid pSV40/neo/rep-cap (Example 2). A total of fifty-two neomycin resistant HeLa cell lines were isolated and characterized.

To test for rep gene function, each cell line was infected with Ad5 and subsequently transfected with pAAV/CMV/SIVrev-gp160. Following Ad5-induced CPE (72 hr), Hirt DNA was isolated and Southern blot analysis performed. Rep gene function was scored positive for cell lines that produced monomeric and dimeric rAAV gp160 sequences. The intensity of autoradiographic signal was used as a relative measure of rep gene expression (1-5+). Ad5 minus control samples never produced rAAV replicative forms. Cap gene proficiency was assayed in a similar manner (Ad5 infection and pAAV/CMV/SIVrev-gp160 transfection), except that a clarified cell lysate was prepared after the development of maximum CPE. HeLa cells were then co-infected with a portion of the clarified cell lysate, Ad5, and wild-type AAV. Hirt DNA was isolated 72 hours later, and hybridization analysis was used to visualize the existence of rAAV/gp160 replicative forms (monomeric and dimeric). In the assay described, the C12 cell line yielded the highest relative proportion of rAAV/gp160/120 sequences.

Results of the characterization assays are presented for eight cell lines are presented in Table 2 wherein the abbreviation "ND" indicates that a value was not determined.

TABLE 2

Cell Line	Rep Function	Cap Function
C2	+++++	+
C12	++++	+++
C16	-	ND
C18	+++	ND
C23	+++	ND
C25	+++	-
C27	++	ND
C44	++++	+

There are two principal uses for the stable cell lines expressing rep-cap sequences: (1) generating rAAV particles if the cell lines are transfected with a rAAV genome and infected with helper virus; and (2) determining rAAV infectious titers. To estimate rAAV infectious titers, these cell lines are co-infected with adenovirus and serial dilutions of the rAAV stock. After maximum CPE, Hirt DNA is isolated and replicative rAAV forms are visualized by Southern blot analysis. End point titration (last rAAV stock dilution to give positive hybridization signal) is then used to determine the infectious titer.

Example 7

The ability of the rAAV produced by HeLa cell line A64 to infect (transduce) and produce SIV gp160 protein in various mammalian cell types in addition to HeLa cells (see Example 4) was assayed. The rAAV (at a multiplicity of

infection of approximately 1) was used to infect cells either in a monolayer or in suspension, depending on the cell type. Three days after rAAV infection, the cells were fixed in acetone/methanol and evaluated for the production of gp160 by indirect immunofluorescence using polyclonal antisera from an SIV-infected monkey. The following cells or cell lines were infected and shown to produce gp160; fetal rat brain cells (neurons and glial cells), mouse 3T3 fibroblasts, mouse vagina, human vagina, human colon, human and monkey lymphocytes and 293 cells. No non-permissive cell type was identified. These results demonstrate that the rAAV produced by the A64 cell line infects a wide range of mammalian cell types and leads to cell surface expression of the SIV envelop gene product, gp160, in the transduced cells.

Example 8

Stable cell lines were generated that produced rAAV carrying the β-galactosidase gene as a gene of interest. These rAAV are useful as positive control to test for expression of a DNA of interest in a target cell or tissue.

A vector like pAAV/CMV/SIVrev-gp160/neo/rep-cap was constructed that included a β-galactosidase gene expression cassette (Clontech, Palo Alto, CA) containing the human CMV promoter, the *E. coli* β-galactosidase gene, and the SV-40 splice/polyadenylation sequence instead of the rabbit β-globin intron, SIV rev and envelope sequences, and rabbit β-globin polyadenylation signal between the AAV ITRs. This β-galactosidase gene expression cassette was cloned in between the AAV ITRs by standard recombinant methods.

Stable HeLa cell lines which produced rAAV containing the β-galactosidase gene (rAAV/β-gal) were generated as described in Example 4 using the foregoing vector.

Example 9

The rAAV/β-gal of Example 8 were used to demonstrate the use of rAAV of the invention for gene transfer into the brains of live mice. rAAV/β-gal was injected directly into the brains of mice and the brains were then examined for evidence of β-galactosidase activity.

Balb/c mice (n = 3; male; 9 months old) were anesthetized and secured on a murine stereotactic platform. Using sterile technique, rAAV/β-gal (1 μl containing 3 X 10^6 infectious units) was injected into the right hippocampus. Additional mice (n = 3) received an injection of diluent as controls. One week after injection, mice were sacrificed by cardiac exsanguination followed by sequential infusion of 50 ml of heparinized phosphate buffered saline, then 50 ml of a mixture of paraformaldehyde (0.5%) and glutaraldehyde (2.5%) in 0.1M phosphate buffer (pH 7.3). Whole brains were removed, post-fixed in the same fixative mixture (2 hours) and frozen in O.C.T. Cryostat sections (10 μm) were placed on poly-L-lysine coated microscope slides and stored at -20°C. Slides were thawed at room temperature, fixed again (5 minutes at 4°C), washed twice in PBS, and transferred to X-gal stain (a substrate for the enzymatic activity of β-galactosidase). After incubation overnight at 37°, slides were washed twice in PBS, counterstained with nuclear fast red, and examined microscopically for blue-stained cells (cells where β-galactosidase was being expressed).

In the brains of the mice injected with rAAV/β-gal, blue-stained cells in the hippocampus were easily detected upon microscopic examination. In the brains of mice injected with diluent (controls), no blue-stained cells were found.

Example 10

Various methods to increase the titer of rAAV generated from stable cell lines which involve providing additional AAV rep and cap genes to the cell lines are contemplated by the invention.

In a first method which demonstrates the usefulness of providing additional rep and cap genes, a producer cell line is transfected with a plasmid containing a helper plasmid carrying AAV rep and cap genes prior to adenovirus infection. Results from experiments in which a rAAV/β-gal producer cell line (H44) was so transfected are presented in Table 3 below.

TABLE 3

Treatment	Viral Yield	IU/cell	Fold increase
Mock transfection	7×10^7	7	0
50 μg pBS/rep-cap	1×10^9	100	14
100 μg pBS/rep-cap	8×10^8	80	11
150 μg pBS/rep-cap	1×10^9	110	16

In a second method, the AAV rep and cap genes are placed on a separate plasmid containing an EBV or BPV origin of DNA replication and a drug resistance marker (hygromycin). The plasmid will be transfected into a producer cell line and new cell lines are then selected on neomycin and hygromycin. This selection pressure will result in stable cell lines which contain both rAAV genomes and multiple copies of the AAV rep and cap genes.

In a third method, the AAV rep and cap genes are cloned into the adenovirus genome in the E3 location under the control of the tetracycline operator.

While the present invention has been described in terms of preferred embodiments, it understood that variations and improvements will occur to those skilled in the art. Therefore, only such limitations as appear in the claims should be placed on the invention.

SEQUENCE LISTING

(1) GENERAL INFORMATION:

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(ii) TITLE OF INVENTION: Adeno-Associated Virus Materials and Methods

(iii) NUMBER OF SEQUENCES: 3

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(v) COMPUTER READABLE FORM:
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(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 4680 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

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(2) INFORMATION FOR SEQ ID NO:2:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 2658 base pairs
(B) TYPE: nucleic acid

(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

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(2) INFORMATION FOR SEQ ID NO:3:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 2571 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

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ACAATAGTCT TTAATCAATC CTCAGGAGGG GACCCAGAAA TTGTAATGCA CAGTTTTAAT    1140
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GGACAAATTA GATGTTCATC AAATATTACA GGGCTACTAT TAACAAGAGA TGGTGGTAAG    1380
GACACGGACA CGAACGACAC CGAGATCTTC AGACCTGGAG GAGGAGATAT GAGGGACAAT    1440
TGGAGAAGTG AATTATATAA ATATAAAGTA GTAACAATTG AACCATTAGG AGTAGCACCC    1500
ACCAAGGCAA AGAGAAGAGT GGTGCAGAGA GAAAAAAGAG CAGCGATAGG AGCTCTGTTC    1560
CTTGGGTTCT TAGGAGCAGC AGGAAGCACT ATGGGCGCAG CGTCAGTGAC GCTGACGGTA    1620
CAGGCCAGAC TATTATTGTC TGGTATAGTG CAACAGCAGA ACAATTTGCT GAGGGCCATT    1680
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Applicant's or agent's file reference number	28335/32634	International application No

INDICATIONS RELATING TO A DEPOSITED MICROORGANISM

(PCT Rule 13*bis*)

A. The indications made below relate to the microorganism referred to in the description on page 6, line s 5-9

B. IDENTIFICATION OF DEPOSIT Further deposits are identified on an additional sheet ☐

Name of depositary institution

American Type Culture Collection

Address of depositary institution *(including postal code and country)*

12301 Parklawn Drive
Rockville, Maryland 20852
United States of America

Date of deposit	Accession Number
1 June 1994	69637

C. ADDITIONAL INDICATIONS *(leave blank if not applicable)* This information is continued on an additional sheet ☐

"In respect of those designations in which a European patent is sought, a sample of the deposited microorganism will be made available until the publication of the mention of the grant of the European patent or until the date on which the application has been refused or withdrawn or is deemed to be withdrawn, only by the issue of such a sample to an expert nominated by the person requesting the sample (Rule 23(4) EPC)."

D. DESIGNATED STATES FOR WHICH INDICATIONS ARE MADE *(if the indications are not for all designated States)*

EP

E. SEPARATE FURNISHING OF INDICATIONS *(leave blank if not applicable)*

The indications listed below will be submitted to the International Bureau later *(specify the general nature of the indications e.g., "Accession Number of Deposit")*

For receiving Office use only	For International Bureau use only
☒ This sheet was received with the international application	☐ This sheet was received by the International Bureau on:
Authorized officer	Authorized officer

Form PCT/RO/134 (July 1992)

GAGGCGCAAC AGCATATGTT GCAACTCACA GTCTGGGGCA TCAAGCAGCT CCAGGCAAGA 1740

GTCCTGGCTG TGGAAAGATA CCTAAAGGAT CAACAGCTCC TGGGGTTTTG GGGTTGCTCT 1800

GGAAAACTCA TTTGCACCAC TACTGTGCCT TGGAATGCTA GTTGGAGTAA TAAATCTCTG 1860

GATGATATTT GGAATAACAT GACCTGGATG CAGTGGGAAA GAGAAATTGA CAATTACACA 1920

AGCTTAATAT ACTCATTACT AGAAAAATCG CAAACCCAAC AAGAAAAGAA TGAACAAGAA 1980

TTATTGGAAT TGGATAAATG GGCAAGTTTG TGGAATTGGT TTGACATAAC AAATTGGCTG 2040

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GCTGTACTTT CTATAGTGAA TAGAGTTAGG CAGGGATACT CACCATTGTC GTTGCAGACC 2160

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ATTGTGGAAC TTCTGGGACG CAGGGGGTGG GAAGTCCTCA AATATTGGTG GAATCTCCTA 2400

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CTCCACATAC CTACAAGAAT AAGACAGGGC TTGGAAAGGG CTTTGCTATA A 2571

Applicant's or agent's file reference number	28535/32634	International application N

INDICATIONS RELATING TO A DEPOSITED MICROORGANISM

(PCT Rule 13*bis*)

A. The indications made below relate to the microorganism referred to in the description on page 7, line s 20-23.

B. IDENTIFICATION OF DEPOSIT Further deposits are identified on an additional sheet ☐

Name of depositary institution

American Type Culure Collection

Address of depositary institution *(including postal code and country)*

12301 Parklawn Drive
Rockville, Maryland 20852
United States of America

Date of deposit	Accession Number
1 June 1994	CRL 11639

C. ADDITIONAL INDICATIONS *(leave blank if not applicable)* This information is continued on an additional sheet ☐

"In respect of those designations in which a European patent is sought, a sample of the deposited microorganism will be made available until the publication of the mention of the grant of the European patent or until the date on which the application has been refused or withdrawn or is deemed to be withdrawn, only by the issue of such a sample to an expert nominated by the person requesting the sample (Rule 23(4) EPC)."

D. DESIGNATED STATES FOR WHICH INDICATIONS ARE MADE *(if the indications are not for all designated States)*

EP

E. SEPARATE FURNISHING OF INDICATIONS *(leave blank if not applicable)*

The indications listed below will be submitted to the International Bureau later *(specify the general nature of the indications e.g., "Accession Number of Deposit")*

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Form PCT/RO/134 (July 1992)

CLAIMS

What is claimed is:

1. A recombinant adeno-associated virus genome comprising adeno-associated virus inverted terminal repeats flanking DNA sequences encoding an immunodeficiency virus protein operably linked to promoter and polyadenylation sequences.

2. The recombinant adeno-associated virus genome of claim 1 comprising the cytomegalovirus (CMV) immediate early promoter, the rabbit β-globin intron, the human immunodeficiency virus rev/envelope sequences, and the rabbit β-globin polyadenylation signal.

3. A recombinant adeno-associated virus genome comprising adeno-associated virus inverted terminal repeats flanking DNA sequences encoding a polypeptide selected from the group consisting of tyrosine hydroxylase, aromatic amino acid decarboxylase, nerve growth factor, brain derived neurotrophic factor, NT-3, NT-4/5, glial derived neurotrophic factor and fibroblast growth factor, wherein said DNA sequences are operably linked to promoter and polyadenylation sequences.

4. A DNA vector comprising the recombinant adeno-associated virus genome of claim 1 or 2.

5. The DNA vector according to claim 4 which is vector pAAV/CMV/SIVrev-gp160/neo/rep-cap (ATCC 69637).

6. A DNA vector comprising the recombinant adeno-associated virus genome of claim 3.

7. A mammalian host cell stably transfected with a recombinant adeno-associated virus genome and with adeno-associated virus rep-cap genes.

8. The mammalian host cell of claim 7 wherein said recombinant adeno-associated virus genome is a recombinant adeno-associated virus genome according to claim 1 or 2.

9. The mammalian host cell of claim 8 which is HeLa cell line A64 (ATCC CRL 11639).

10. A mammalian host cell stably transfected with a recombinant adeno-associated virus genome and with adeno-associated virus rep-cap genes, wherein said recombinant adeno-associated virus genome is a recombinant adeno-associated virus genome according to claim 3.

11. A method for producing infectious recombinant adeno-associated virus comprising the step of infecting a host cell according to claim 7 with a helper virus of adeno-associated virus.

12. A method for producing infectious recombinant adeno-associated virus comprising the step of infecting a host cell according to claim 8 with a helper virus of adeno-associated virus.

13. A method for producing infectious recombinant adeno-associated virus comprising the step of infecting a host cell according to claim 10 with a helper virus of adeno-associated virus.

14. Infectious recombinant adeno-associated virus produced by the method of claim 11.

15. Infectious recombinant adeno-associated virus produced by the method of claim 12.

16. Infectious recombinant adeno-associated virus produced by the method of claim 13.

17. A vaccine composition comprising the infectious recombinant adeno-associated virus of claim 14.

18. A vaccine composition comprising the infectious recombinant adeno-associated virus of claim 15.

19. A method for immunizing a host against human immunodeficiency virus comprising the step of administering an immunity-inducing dose of a vaccine composition according to claim 17 to said host.

20. A method for immunizing a host against human immunodeficiency virus comprising the step of administering an immunity-inducing dose of a vaccine composition according to claim 18 to said host.

21. A method for treating a neurodegenerative disorder comprising the step of administering a therapeutically effective dose of an infectious recombinant adeno-associated virus according to claim 16 to a host exhibiting said neurodegenerative disoder.

22. The method of claim 21 wherein said neurodegenerative disorder is selected from the group consisting of Alzheimer's disease, Parkinson's disease, and Huntington's disease.

23. The method of claim 11 wherein said helper virus contains adeno-associated virus rep-cap genes inserted in its genome.

24. The method of claim 12 wherein said helper virus contains adeno-associated virus rep-cap genes inserted in its genome.

25. The method of claim 13 wherein said helper virus contains adeno-associated virus rep-cap genes inserted in its genome.

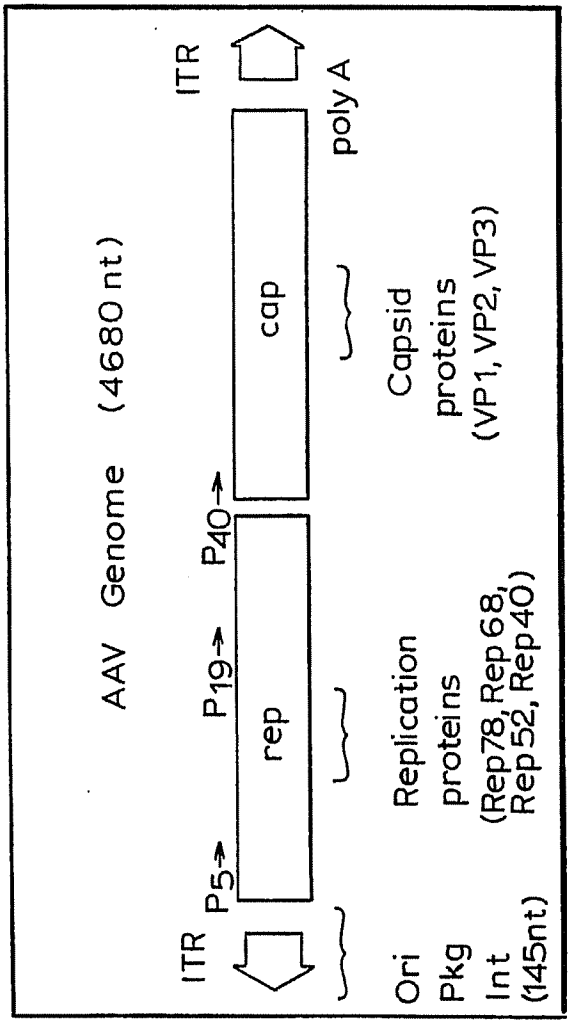

AAV Genome (4680 nt)
ITR
P5
P19
P40
rep
cap
ITR
poly A
Ori
Pkg
Int
(145nt)
Replication proteins (Rep78, Rep68, Rep52, Rep40)
Capsid proteins (VP1, VP2, VP3)

FIGURE 1

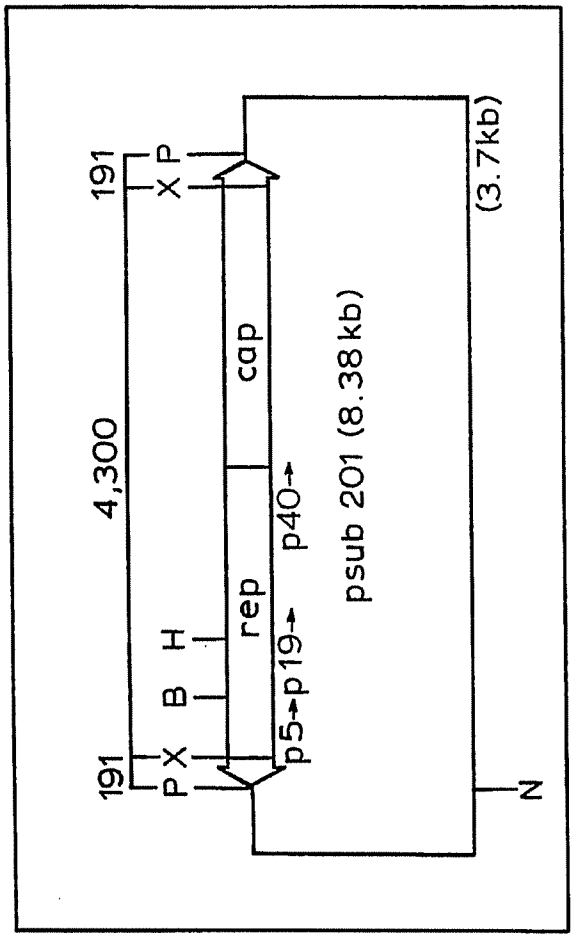
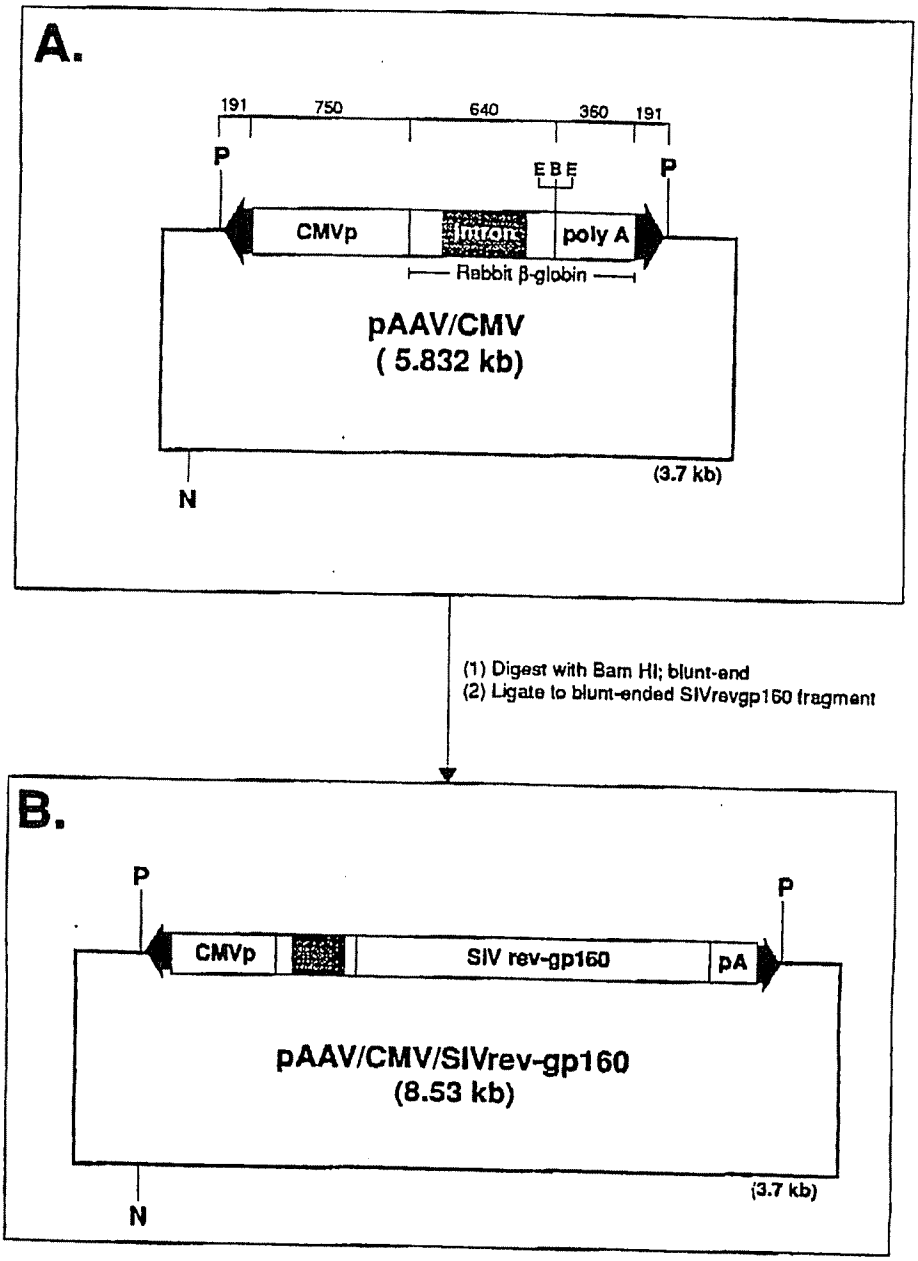


FIGURE 2

FIGURE 3


A.
191
750
640
360
191
P
E B E
P
CMVp
Intron
poly A
Rabbit β-globin
pAAV/CMV
(5.832 kb)
(3.7 kb)
N
(1) Digest with Bam HI; blunt-end
(2) Ligate to blunt-ended SIVrevgp160 fragment
B.
P
P
CMVp
SIV rev-gp160
pA
pAAV/CMV/SIVrev-gp160
(8.53 kb)
(3.7 kb)
N

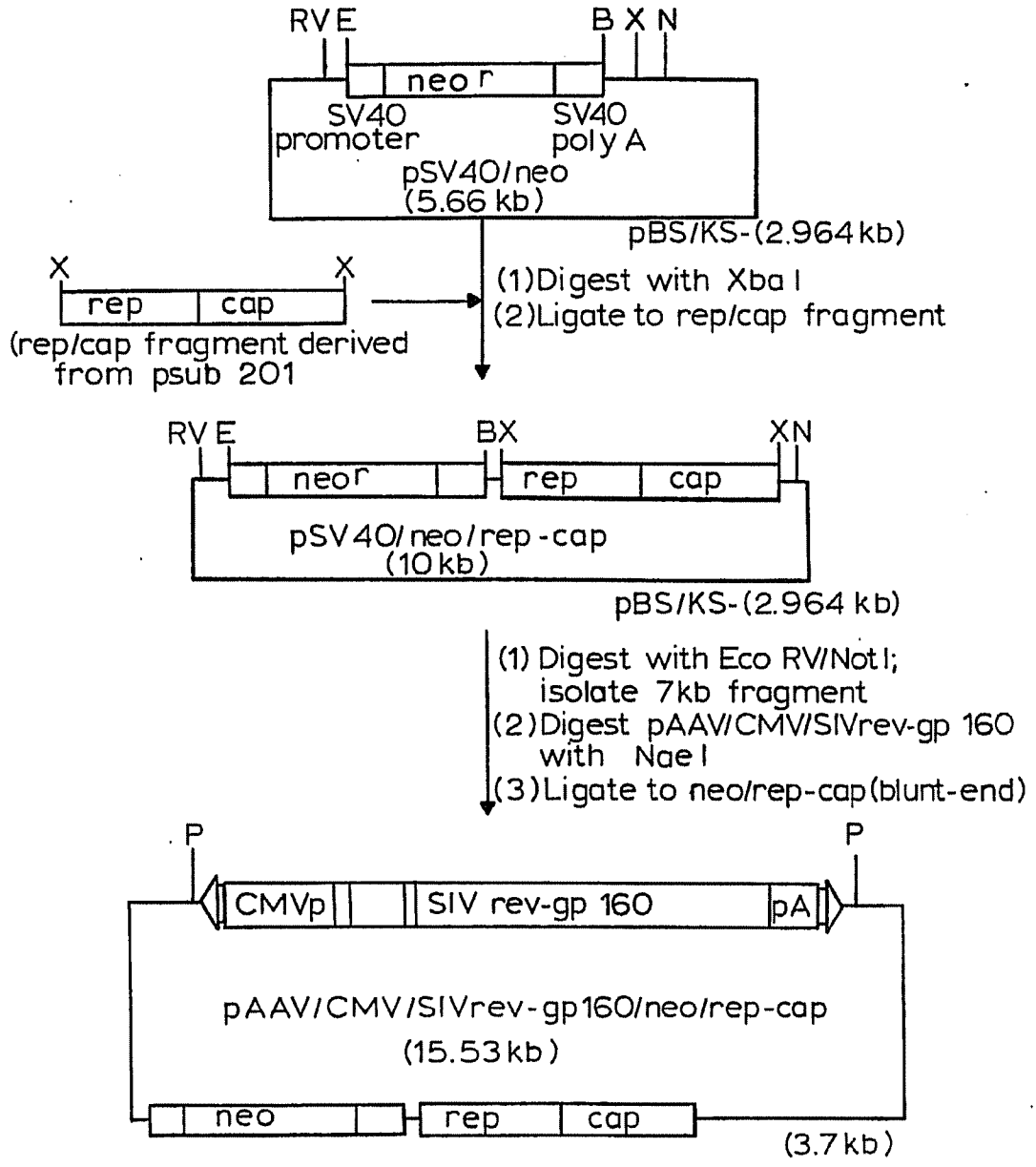

RV E
B X N
neo r
SV40 promoter
SV40 poly A
pSV40/neo (5.66 kb)
pBS/KS-(2.964 kb)
X
X
rep
cap
(rep/cap fragment derived from psub 201
(1)Digest with Xba I
(2)Ligate to rep/cap fragment
RV E
BX
XN
neor
rep
cap
pSV40/neo/rep-cap (10 kb)
pBS/KS-(2.964 kb)
(1) Digest with Eco RV/Not I; isolate 7kb fragment
(2)Digest pAAV/CMV/SIVrev-gp 160 with Nae I
(3)Ligate to neo/rep-cap(blunt-end)
P
P
CMVp
SIV rev-gp 160
pA
pAAV/CMV/SIVrev-gp160/neo/rep-cap (15.53 kb)
neo
rep
cap
(3.7 kb)

FIGURE 4

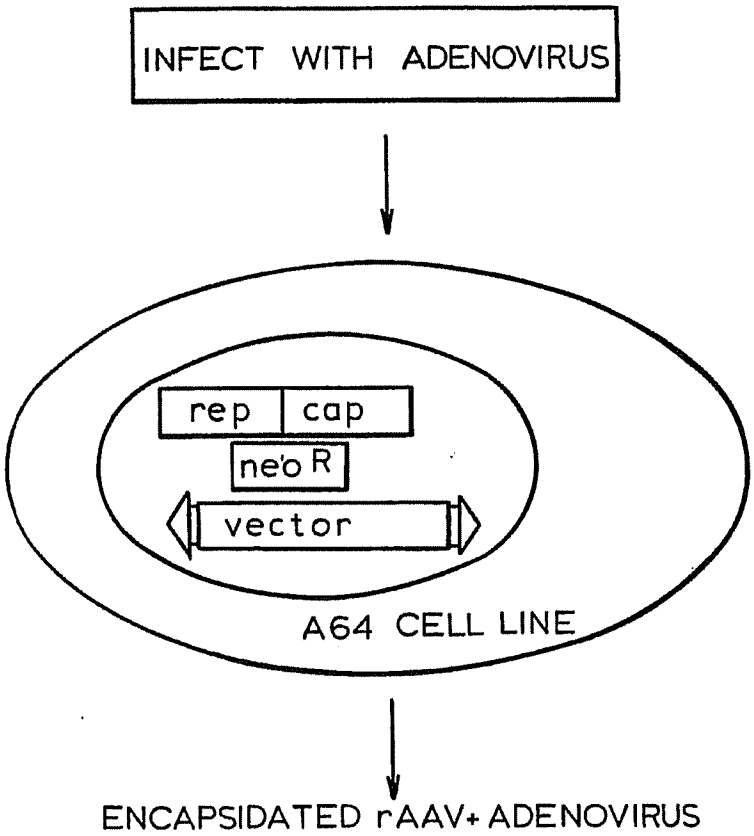

INFECT WITH ADENOVIRUS
rep
cap
neo R
vector
A64 CELL LINE
ENCAPSIDATED rAAV+ ADENOVIRUS

FIGURE 5